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The Foundation of Distributed Ledger Technology for Supply Chain Management

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Abstract

Distributed ledger technology (DLT) appears to be one of the most promising technologies in the field of supply chain management (SCM). However, as the technology is still evolving, only limited empirical evidence has been analyzed, managers and scientific scholars alike seek to understand how DLT can help improving SCM. This study aims to shed light into the current DLT applications in SCM to identify the foundation of the technology for SCM and uncover what DLT brings to the table. It develops seven foundational characteristics of DLT in SCM that describe both the nature of DLT and its characteristics for SCM. The study reveals that DLTs are interorganizational information systems that are diverse in their realizations and enable modular platform ecosystems. Nowadays application in SCM build on steady data availability, selective transparency, high authenticity and a source of mutual trust.

1. Introduction

Distributed ledger technology (DLT) is at the center of attention in the field of supply chain management (SCM) [34]. Although the excitement in the media and the world of science has cooled down lately as the novel technology has almost reached the trough of disillusionment on Gardner's hype cycle, the interest in DLT in SCM remains significant [27]. Following Deloitte's survey on DLT, organizations have invested a substantial amount of money in DLT initiatives [28]. According to this study, over 160 initiatives have been started in the last four years to explore the use of DLT in the field of SCM. DLT's decentralized architecture appears to be tailor-made for the interorganizational structure of supply chains. Hence, media and science have proclaimed the great potential of DLT with attributes such as "disruptive", "radical" or "drastic" [e.g. 4]. Nevertheless, the scene is young and the technology is still under development. Furthermore, the success of the started DLT initiatives is not yet fully apparent due to the novelty and confidentiality of multiple projects. The study reveals that the initiatives are dominated by large supply chain actors and only a limited number of small and medium sized enterprises (SMEs) have explored the technology. However, a large-scale implementation in the supply chain will require also SMEs to use the technology. But at this point in time, especially managers of SMEs are left alone with their assessment on the potential of the technology. Often, they are wondering what value the technology can deliver, also in comparison to other, established solutions. So far, little research has analyzed empirical data of DLT initiatives to help practitioners with their struggle. Knowing that contemporary supply chains face multiple challenges, included but not limited to a lack of transparency on products conditions and history, limited trust between transaction partners or inefficient information flows that thwart the flow of physical goods, DLT appears to have the potential to address these challenges [e.g. 1, 5, 31]. However, it is the explanation of "how" DLT can address these challenges that is the puzzle for decision makers. Due to the technology being characterized by a certain degree of complexity and immaturity, the transfer of pure technical concepts such as different consensus mechanisms, cryptographic encryption and scalability issues, reduce the understandability of the technology. Thus, this study seeks to help practitioners that have not explored DLT to understand the value of DLT by identifying the foundational characteristics (FC) of DLT for SCM. Therefore, the study defines the following research question:

RQ: What are the foundational characteristics of DLT in SCM?

This research question requires the first large-scale, empirical study to derive the FCs, as practitioners' assessment requires empirical evidence, which is currently lacking.

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2. Theoretical background

2.1 Supply chains and its management

Supply chains form networks of multiple organizations that jointly seek to move a product from raw materials to end customers [8]. Within these networks, organizations are connected by the flow of physical products, rights, money and information. The management of supply chains seeks to plan, control and implement efficient value creation within and across organizations' boundaries [24]. Thus, in order to manage supply chains, the flow of information across company boundaries is vital. With the emergence of novel technologies such as the internet or electronic data interchange (EDI), the ways to manage supply chains have changed. These developments of SCM have mainly addressed the information flow between organizations. Thereby, they represent forms of interorganizational information systems (IOIS) that aim at facilitating the information flow across organizational boundaries [16]. Especially with increasing digitization, the call for improved information flow is getting louder [15]. Despite the emergence of IOIS, their use has not eliminated all the challenges connected to the information flow in supply chains. The efficient information flow is still thwarted by a lack of standards to exchange information and the limited willingness to share information with other organizations [37]. In consequence, this leads to a lack of transparency which results in operational inefficiencies [2]. In addition, SCM battles with a lack of trust between the partners, as information is only available or verifiable to a limited degree [20]. The negative effects from the lack of trust vary from higher transaction costs that include risk surcharges to withdrawal of customers and actors [30]. Yet again, novel technologies including DLTs promise to bring improvement for the flow of information in supply chains and thus offer chances to tackle these issues. Inter alia, the most promising are DLTs [34].

2.2. DLT in SCM

While having emerged as underlying technology behind Bitcoin, DLT has found its way into other fields besides finance. Among others, the field of SCM is a promising field for DLT, in which the technology aims to resolve the above-mentioned challenges [34]. DLT describes a set of technologies that are characterized by its decentralized ledger of data that is shared and agreed upon by a peer-to-peer network [3]. Among these technologies, the blockchain technology (BCT) is used for cryptocurrencies such as Bitcoin, which is the most commonly known representation of DLT. However, other realizations such as directed acyclic graphs (DAGs) are also a form of DLT. Among the more popular examples are IOTA or Byteball. This study focuses on these two forms of DLT.

Blockchains have to be distinguished in terms of access right (public vs. private: Who is allowed to participate in the network and can see the transactions) and writing rights (permissioned vs. permissionless: Who is allowed to add blocks and validate them). While traditional Ethereum and Bitcoin blockchains are public and permissionless, private and permissioned blockchains such as Hyperledger and Corda are often used in SCM. In general, BCT allows the storage of data in data blocks and distributes these blocks within the peer-to-peer network [5]. However, before the data is stored and distributed in the network, the ledger validates the correctness of a data record that is issued for storage. Afterwards, the data is verified by a consensus mechanism via miners in the network. Once both validation and verification is achieved, the data is encrypted in a block and distributed among the network [32]. Consequently, each network member chains the new data block automatically to the previous blocks by using a header, which points to the pervious block [7]. Hence, each network participant holds the exact same ledger in the form of a linear chain of data blocks [13]. Therefore, in the instance that a single ledger within a network is not congruent to the others, it has been manipulated and can be detected immediately. [35]. Moreover, the distribution of data in near real-time allows for steady accessibility of data without a single point of failure [19].

DAGs are directed graphs (incl. nodes and edges) without cycles that are used to store data records. Within these graphs, it is impossible to reach a specific node within the graph again. The edges in the graph constitute the links between the nodes, more precisely the parent-child relationship between the data nodes [22]. Like the header in a blockchain, the incoming directed edges carry out the typological ordering of the data graph. However, unlike blockchains, the data is not stored in blocks that are chained together, but rather in the nodes within the graph. One advantage of DAGs in comparison to BCT is that DAGs do not rely on mined blocks and so they are not limited by data storage size nor the speed of the miners [6]. This also leads to reduced energy consumption as typical mining operations are energy consuming [21]. Another advantage is that the improved transaction volume that can be processed enhances scalability, which is particularly important for applications that require both volume and velocity [6]. Compared to BCT, this is the result of the verification process within the DAG.

While BCT has to verify the entire chain of blocks, namely the longest chain, DAGs only verifies a pre-defined number of nodes (e.g. IOTA the last two transactions), reducing the verification time [33].

Following these technical concepts, DLT enables the immutable and cryptographically secured storage of data, as neither the chain of blocks nor a direct graph can be altered without the notice of others within the peer network [17]. In addition, DLTs allow to trace back every transaction by following the chain respectively directed edges [36]. While this summarizes the literature in the IS field, extant literature on DLT in SCM focuses on the potentials and benefits of the novel technology for SCM. Wang et al. [34] derive disintermediation, transparency, security and automation as the four key benefits from extant DLT literature in SCM. In addition, their study goes on to present the findings of expert interviews. Hereby, they explore improved supply chain visibility/transparency, secure information sharing and building of trust as well as operational improvements as perceived benefits of BCT in SCM. While transparency and security are mentioned both in literature and by the experts in the study of Wang et al. [34], the other benefits differ. In their conceptual work, Saberi et al. [31] present decentralization, trust, security, auditability, automation via smart contracts and transparency as key attributes of BCT in SCM. Kamble et al. [17] list transparency, immutability, trust and disintermediation to describe the benefits of BCT for SCM. Abeyrath and Monfared [1] illustrate the improved transparency, automation and disintermediation of BCT for manufacturing. Blossey et al. [7] present transparency, validation, automation and tokenization as key features of BCT in SCM. Following the authors, tokenization allows to create tokens that represent assets within the supply chain that can be exchanged between supply chain actors. When looking at BCT to improve procurement processes, Kolb et al. [18] reveal that improvement is achieved by transparency, decentralization, immutability, trust, automation, security and accessibility of BCT. In their case of BCT-based bill of ladings, Nærland et al. [26] present transparency, security, decentralization, immutability, automation and validation as key characteristics of DLT in SCM.

While some of the above mentioned characteristics (transparency, security, trust) of DLT in SCM are found in multiple literature contributions, as illustrated in Table 1, others are only found in individual contributions. Only transparency is found in all contributions. With a view on the gap between theoretical and practitioner's entries in the writings of Wang et al. [34], research calls for more empirical evidence of the foundation of DLT in SCM in order to understand the current use of DLT and pave the way for future deployment of the technology in our field of study. In addition, extant literature does not draw relations between these characteristics. Rather they stand side by side with no link. This does not provide more understanding on the interplay as some characteristics appear to be basis for other such as security for immutability.

Table 1. DLT characteristics in SCM literature

	Wang et al. 2019	Saberi et al. 2018	Kamble et al. 2018	Abeyrath and Monfared 2016	Blossey et al. 2019	Kolb et al. 2019	Nærland et al. 2107
disintermediation	x		x	x			
transparency	x	x	x	x	x	x	x
security	x	x				x	
automation	x	x		x	x	x	x
trust	x	x	x			x	
decentralization		x				x	x
auditability		x					
immutability			x			x	x
validation					x		x
tokenization					x		
accessibility						x	

3. Methodology

In order to address the research question, the study uses a qualitative approach in two phases. The first phase consists of data collection and analysis of secondary data as an inductive approach to develop the initial FCs. Following the inductive phase, the study includes a confirmatory second phase that draws on case interviews. This approach was chosen as it allows to validate the findings from the inductive phase, as these only build onto the secondary data. In our first phase, I searched for DLT initiatives in SCM that were either proof of concepts or pilot projects. Therefore, I defined a list of search terms to identify DLT initiatives in SCM. This list contained two word sets that represent both the technology DLT and the field of usage SCM as presented in Table 2. I then combined both word sets for our search process.

Table 2. List of search terms

word set	search terms
DLT	"distributed ledger technology" OR "shared ledger" OR "decentralized ledger" OR "blockchain technology" OR "block directed acyclic graph" OR "transaction-based directed acyclic graph"
AND	

SCM	“supply chain” OR “supply chain management” OR “supplier networks” OR “value chain” OR “interorganizational”

In addition, I defined the selection criteria in order to allow proper data analysis as follows:

- Usage of DLT in SCM based on the understanding of the supply chain operations reference (SCOR) model
- Availability of multiple different data sources to allow data triangulation and reduce biases
- Availability of data in English to enable data analysis

Afterwards, I screened the databases Factiva and LexisNexis, searched for press releases, blogs, conference and event programs as well as webpages for entries of our search terms. Initially I identified 162 DLT initiatives in SCM in our screening phase between February 2019 and May 2019. Subsequently, I applied the selection criteria on these 162 initiatives. The last criteria especially led to a reduction of initiatives as I identified a number of Asian projects but were unable to find sufficient data in English for further analysis. Thereby, I reduced the list to 136 DLT initiatives. After this identification step, I started to collect data from different sources. For eight initiatives, I was not able to gather enough data to allow sufficient data analysis to address the research question. Thus, I had to limit the scope to 128 DLT initiatives in SCM.[1]

Before analyzing the data to address the research question, I prepared an Excel spreadsheet that listed context information on each initiative. This contained data on the motivation of the project, the target, the role of DLT, additional technologies, the involved parties including the DLT provider and the DLT users, contact persons when detectable, the project status, the year of initiation and listed a link to the data sources that I had identified previously. All 128 DLT initiatives were started between 2015 and 2019. The majority started in 2018 (54 initiatives). Geographically, I identified initiatives all over the world, with the most being launched in the United States of America, followed by China and the United Kingdom. The DLT initiatives were started in 16 different industries, with the most started in food (46), logistics (21) and trade financing (19).

For our data analysis for the first phase, I combined both qualitative and quantitative analysis. For our qualitative analysis, I drew on grounded theory [12] and followed the coding approach of Gioia et al. [11]. This entailed first order coding with the terminology of our secondary data source for each individual initiative. Based on these first order codes, I identified emerging topics in our data of each individual DLT initiative. Afterwards I merged these codes to second order codes on a cross-initiative basis. These codes disclosed the different applications and the characteristics of DLT. Thereby, I created an unstructured list of both applications of DLT in SCM and characteristics of DLT in SCM. Subsequently I matched DLT initiatives with their applications and characteristics of DLT in an Excel spreadsheet. I used this spreadsheet to run quantitative analysis and calculate relative frequencies of applications and proposed FCs. In addition, I analyzed the characteristics in depth to address the research question. Therefore, I drew on the rich data of each code to understand the context. This helped us to identify links to other characteristics to reveal dependencies. Thereby, I was able to identify first and second level characteristics. While the first level characteristics were directly linked to the specifications of the deployed DLT, the second level characteristics proved to be results of combinations of the first level characteristics. Based on the context of the emerged codes, I developed a draft for an initial framework to illustrate the relationships between the different characteristics.

Based on these initial findings, I started the confirmatory phase two. The goal of this phase was to validate the findings (incl. the proposed characteristics and the initial framework) from our exploratory phase. The in-depth interviews were also necessary to discuss the relationships between the DLT characteristics that were illustrated in our initial framework. Therefore, I contacted all initiatives and asked for interviews of approx. 45 minutes. I contacted both DLT providers and DLT users. I received 26 positive replies and arranged calls. The interviewees are listed in Table 3. In some cases, I was able to talk to both DLT provider and DLT user of a single initiative, as marked in the table. The majority of the interviews were conducted via phone or Skype, due to unreasonable travel distances. During the interviews, I applied an interview instrument. The interviews lasted between 40 and 75 minutes and were recorded and transcribed. Afterwards I analyzed the transcriptions following Gioia et al. [11]. In this step, I analyzed the elaborated first and second level codes again, as described in our exploratory phase. Afterwards I analyzed the codes and identified confirmatory and contractionary codes to the proposed characteristics and the initial framework. Based on our data analysis, I refined both the proposed characteristics and the initial framework. This led to the FCs that are described in section 4 and the framework, illustrated in Figure 1. While most of the

[1] The data set can be provided upon request by the author.

relations between the characteristics that represent dependencies were confirmed, I eliminated the relations that only appeared in over 50% of the interviews. I defined 50% as the threshold to ensure that the heterogeneity of the applications was taken into account as well as to be able to derive generalizable findings from our data.

Table 3. Interviewee overview

ID	Function of interviewee	Application of DLT initiative
P1	COO	Proof of origin*
U1	Managing Director	
U2	Head of Development	
P2	CEO	Proof of origin*
U3	Purchasing Director	
P3	CEO	Trade financing*
U4	Project Manager	
P4	CEO	Proof of origin*
U5	Head of SCM	
P5	Business Architect	Proof of origin and trade documentation*
U6	Project Manager	
P6	CMO	Trade financing
P7	Business Developer	Proof of origin
P8	Business Developer	Trade documentation
P9	COO	Trade financing
U7	Project Leader Banking	Proof of origin and trade financing
U8	Head of SCM	Proof of origin
U9	Project Managers SCM	Proof of origin
U10	Supply Chain Innovation Specialist	Proof of origin
U11	Head of Outbound Logistics	Proof of origin and trade documentation
U12	CFO	Proof of origin and trade financing
U13	Financial Officer	Trade financing
U14	Project Manager	Trade financing
U15	Supply Chain Manager	Trade financing
U16	Export Manager	Trade documents
U17	CFO	Trade documents

P DLT provider
U DLT user
* DLT initiative with user and provider interview

4. Results

4.1 The nature of DLT initiatives in SCM

Based on the data analysis, all studied DLT initiatives are forms of IOIS following the definition of Johnston and Vitale [16] and Lyytinen and Damsgaard [23]. They are initiated to enhance the information flow across organizational boundaries and are jointly used by multiple organizations. Similar to other IOIS such as electronic data interchange (EDI), they require standards in order to allow an interorganizational use of data [10]. However, unlike other IOIS, DLT solutions distribute data to entire networks [4], not just to a selected number of partners. Consequently, the data is distributed and stored within the entire DLT network, leading to a high availability of information. As the empirical data revealed, the DLT solutions draw on networks consisting multiple partners and thereby enable the integration of multiple supply chain partners. At the same time DLT address the issue of data governance in supply chains, as data privacy and ownership of data is becoming more important due to the pursuit to protect intellectual property and reducing information asymmetry in supply chains. While DLT's effect to reduce information asymmetry has been analyzed by Roeck et al. [30], the IOIS aspect is not discussed in extant literature and practitioners have only little understanding, that DLT project require substantial collaboration along the supply chain. Hence, the first FC of DLT is defined:

FC1: DLT is an IOIS for managing supply chains.

When studying these IOIS more closely in a supply chain context, the data reveals that the initiatives are quite different. While some include only a small number of supply chain actors along the physical flow of goods, others aim at integrating entire supply chains or even build industry platforms, including competitors on multiple levels of the supply chain. At the same time, the initiatives also vary in the used technologies. Most initiatives use BCTs, with the Ethereum (public blockchain) and Hyperledger (permissioned) blockchains as the front-runners. However, other DLTs such as Corda for financial applications or DAGs[2] for internet of things (IoT) networks are used in more recently started projects. The selection of the underlying technology is aligned to the target of the initiatives. The studied DLT initiative evidence a great variety of targets. Sixty-eight (53%) initiatives aim at providing traceability for physical products. In addition, the most frequently described targets in the initiatives were near real-time data distribution, increasing data security and digitizing trade documents as well as preventing product counterfeits and financial fraud. Hence, the initiatives in the field of SCM show great heterogeneity, a FC that is overlooked by extant literature. At the same time, practitioners see currently only a limited number of DLT use cases for them and fear to make a wrong decision for the future. However, DLT offers the opportunity to add various applications.

FC2: DLT enables heterogeneity in terms of user networks, underlying technologies and targets in supply chains.

This heterogeneity manifests itself as well in the different applications of DLT in SCM. DLT is not an application in SCM but it has multiple applications in the field. The most frequently used application of DLT in SCM is to provide a *proof of origin* in order to display the chain of custody. The majority of the

[2] Seven of the initiatives used a DAG.

studied DLT initiatives (75%, in total 96 initiatives) include such an application. Furthermore, DLT applications to enable *trade and inventory financing* (13%) and to *exchange of trade documents* (11%) are the second and third most frequent applications that were found in the data set. Other applications are individual applications. Hence, this leads to an observation: Although there are a large number of DLT initiatives in the field of SCM, there are currently only a few common applications for DLT. Primarily, the focus is clearly on enhancing transparency with DLT at the time of this writing. However, 19 out of 26 interviewees, both DLT solution providers and the users, have expressed that other applications will also be a part of further development and will be added to existing applications. They see enhancing transparency as a first application to test the technology and as a cornerstone to enable more applications such as financing solutions. Fourteen DLT initiatives (11%) already enable multiple applications. Thus, the DLT solutions are perceived as platform ecosystems that enable multiple applications. This leads to another FC:

FC3: DLT enables platform ecosystems that combine different applications in supply chains.

Both FC2 and FC3 emphasize the capability of DLT to integrate multiple actors and multiple functionalities. This integrative nature is an important aspect in nowadays dynamic supply chains that require to work together with multiple actors and adapt to changing requirements.

After having described the nature of DLT in SCM, this study goes on to analyze the applications on a deeper level to identify the characteristics that are used for the different applications. Following the heterogeneity of DLT, the analysis is conducted on the level of applications, before an aggregation on a SCM level is made. Therefore, the study presents the findings of the three major applications to focus on the relevant applications at this time.

4.2 Characteristics of DLT applications

DLT applications that aim at providing a *proof of origin* or illustrating the chain of custody build on the four characteristics transparency, authenticity, availability, and trust that are enhanced by DLT. First, they are based on transparency that is achieved by DLT's ability to distribute information frictionless to all network members, visibility of transactions and the ability to trace back any information once entered in the distributed ledger. DLTs capability to enhance transparency is explicitly listed as reason to apply DLT in 88% of the 96 initiatives. Moreover, 70% of the initiatives list DLT's ability to enable authenticity as reason to deploy DLT. Authenticity is enabled by the immutability of entered data within the ledger and the integrity that is enabled by the validation and verification of data before entered in the ledgers as well as the cryptographically secured data within the distributed ledger. Furthermore, 32% of the studied initiatives see also DLT's high availability as an important characteristic for providing a proof of origin. DLT's decentralization is paired with fast information accessibility, which increases the availability of information. In addition, trust is listed in 31% of the initiatives as a fourth characteristic. The confirmatory interviews revealed that trust is a result of the three characteristics transparency, authenticity and availability. Transparency and availability enable visibility of data from a quantitative perspective, while authenticity ensures correctness of data and thereby improves the quality of available data. This relation is not discussed further in the DLT literature, as trust is seen on the same level such as transparency [34].

DLT applications used to improve *trade and inventory financing* in supply chains include the offering of financial services such as working capital solutions as well as facilitating financial investments by making financial documents such as letter of credits available. In 77% of the initiatives, transparency is listed as argument to deploy DLT. As illustrated in the first application as well, the ease to distribute data via DLT is the main advantage. Moreover, the improved availability by DLT's capabilities to communicate information within the network is listed in 53% of all the initiatives as reason to deploy DLT. Only 35% of the initiatives see authenticity of data as argument to use DLT, while only 24% of the initiatives list DLT enhanced trust as reason. The interviewees reported that the initiatives aim to improve speed and simplify *trade and inventory financing* rather than preventing financial fraud.

For applications that aim at *exchanging trade documents*, the improved availability of data is the most commonly mentioned argument for DLT (87%). Following the statements of the interviewees, these DLT solutions allow them to digitize and provide information such as bill of ladings to multiple partners in near real-time. By this, DLT enhances transparency, as selected supply chain actors such as customs authorities can view required documents. Thus, 67% of the initiatives list DLT enhanced transparency as argument for their DLT use. In addition, authenticity (60%) and trust (53%) are arguments for deploying the technology. While this sub-section has presented the characteristics of DLT for the three major applications in SCM individually, the study goes on to analyze these characteristics and their interplay across these cases to carve out the foundations of DLT for SCM.

4.3 Foundations of DLT for SCM

Based on the analysis on the application level, the data reveals that although the order and importance may be different, the four main characteristics transparency, availability, authenticity and trust are found in all applications. With a closer look, the data reveals characteristics on two different levels. The first level characteristics are directly associated to DLT as a technology. They enable second level characteristics, which were identified as main characteristics in the previous sub-section. The following list presents the first level characteristics to each second level characteristic:

- Transparency: traceability of transaction data, visibility of transaction data, frictionless distribution of data
- Availability: near real-time data distribution, decentralized data storage, stable accessibility
- Authenticity: validation and verification of entered data, immutability of stored data, cryptographically secured data
- Trust: auditability and accountability of transaction data

Based on our secondary data and the confirmatory interview data, both first and second level characteristics show dependencies that are illustrated with arrows in Figure 1. The connections of first level characteristics are illustrated with dashed arrows. For example, DLT provides the ability to trace back transactions. This allows to hold actors accountable for their transactions. The dashed arrow illustrates this causality. Following these dependencies, the second level characteristics reveal dependencies as well, which are represented in normal arrows. By enabling improved data availability, enhanced transparency can be achieved with the use of DLTs. Characteristics in italic are not natively provided by public BCT.

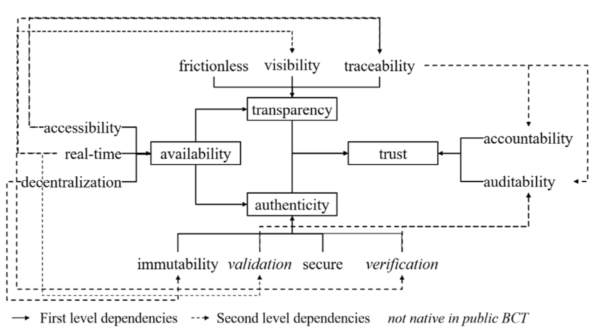

Figure 1. Framework of DLT characteristics

As illustrated in the framework in Figure 1, the availability based on near real-time data distribution, decentralized data storage and stable accessibility is an enabler for transparency and authenticity. As stated by DLT user 8: "*Our DLT solution provides all network members to access the required data which enables to see data without delay or issuing a request and also trace back who participated in a trade*". Thereby, he emphasizes the enabling role of stable accessibility and near real-time data distribution for each partner to enhance visibility and traceability of transaction data. Thus, each supply chain partner has the same availability of data, which is the basis for transparency. However, DLT enables to disclose information only to required network members and this does not require full transparency to all partners (e.g. as IBM's different blockchain channels). This enables selective transparency. In addition, near real-time data distribution and decentralized data storage empower the immutability of data. Furthermore, near real-time data distribution is an important requirement for validating and verifying entered data, as stated by DLT user 4: *"Blockchain enables to communicate transactions via peer-to-peer communication in near real-time. Only thereby, we can validate and verify transaction securely. Not having this speed would cause a substantial security issue as they could be altered before chained to the last block."* In addition, transparency and authenticity contribute to enhanced trust, while availability and trust do not have a direct link. DLT based traceability enables that transaction and the involved parties (even if only as a pseudonym) can be traced back and thereby held accountable. At the same time, this ensures improved auditability of transactions. Immutability, security, validation and verification enable to audit transactions and thus build up trust between transaction partners. Hence, DLT enhances mutual trust between supply chain partners. Following this data analysis, DLT initiatives present four additional FCs that add to the three FCs.

With the increasing digitization in contemporary supply chains, data availability across company boundaries becomes more and more important [15]. At the same time, the call to increase transparency by making data available to other supply chain actors is getting louder [38]. DLT addresses the need of data availability in two ways. First, the fast distribution of data within a DLT network enables timely accessing and processing of data that builds a cornerstone for digitization. As DLT user 2 stated: *"Our [DLT] solution enables to exchange data within split seconds and thus allows our partners to access all required data when they needed. This speeds up their inspection processes; they can decide in advance how to process the shipments."* Second, the decentralization of data within a DLT network eliminates the chances for a single point of failure and thereby leads to high availability of data. Thus, DLT creates a steady availability that empowers digitization in supply chains and builds a basis to address the demand for increased transparency within supply chains.

FC4: DLT is a source of steady data availability in supply chains.

DLT enables to disclose information only to specific peers. The realization depends on the type of DLT. For public blockchains, each transaction is visible for every network member. In this case, the network members have pseudonyms, so that only involved parties have full transaction visibility, while the outside members see only a transaction between unknown network members. By providing a private key that allows defined organizations within the network to access data and identify its affiliation. Private blockchains allow transaction visibility only to a closed circle that is often limited to certain industry or supply chain channels. Some of the investigated DLT initiatives (mostly private DLTs) wish to have transparency only in a certain direction. Other initiatives enable to create different access roles for specific network members such as customs authorities or port operators. Unlike in centralized databases, no single administrator can change these roles. DLT requires a joint agreement to adjust these roles and thus has a democratic component to govern the distribution of data and the transparency within supply chains. Thus, DLT enables a selective transparency depending on the position in the supply chain or the role, which is crucial for contemporary supply chains that depend on transparency while organizations do not wish to disclose too much information at the same time [25]. In DLT-based industry platforms, the decentralized availability of data and the enhanced transparency is critical. The enhanced transparency is perceived as a benefit according to all interviewees. However, when looking at DLT-based industry platforms that include competitors, our interviewees emphasize that transparency has to have its limits. Thus, these DLT initiatives build on private channels in the distributed ledger. The data within these channels is only distributed to pre-selected network members. Thus, selective transparency is achieved by establishing private channels in DLT networks. This is a requirement to create industry platforms. These establish standardization, thereby facilitating the processing of information and avoiding redundant systems. In the words of DLT provider 2: *"In the long run, there will be more industry platforms with private channels and defined roles that dictate the scope of individual transparency, because you will not get suppliers to join five or ten different DLT solutions at the same time."*

FC5: DLT is a source of selective transparency in supply chains[3].

While having data availability is central in contemporary supply chains, the quality, and more precisely, the correctness of data is crucial to achieve transparency as well [2]. DLTs as private blockchains, provide mechanisms to validate the correctness of transaction data (e.g. by checking the consistency with historical records in the ledger) and to verify (e.g. with consensus mechanisms) before entering data in the distributed ledger. Public blockchains do not natively include validation and verification. However, only few initiatives in the field of SCM are built on public blockchains such as the original Ethereum blockchain[4]. Thus, private DLTs provide a quality gate that improves data authenticity. Once the data passes the quality gate and is stored in the distributed ledger, it is secured from unauthorized access by encryption and is immutable due to the decentralization. This leads to high authenticity of data when private DLTs are used in an interorganizational setting.

FC6: DLT is a source of high authenticity in supply chains.

Based on transparency and authenticity, DLT improves trust between transaction partners. The combination of both characteristics enables to trace back transactions and thereby achieve accountability and auditability. As DLT user 6 points out: *"We [the DLT consortium] restore trust with this [the DLT initiative]. Every actor is able to trace back in case of incidents and identify the involved party. Everybody in the network knows that. So nobody will play dirty on purpose."* Following this line of argumentation, DLT builds a basis for trust, based on the improved accountability and auditability. Extant research has identified the length of relationships as important to build up trust in supply chains [14]. With the use of DLT, trust can be built faster. Hence, DLT enables mutual trust between supply chain partners, even if they do not share a long-term relationship.

FC7: DLT is a source of mutual trust in supply chains.

In addition to the studied applications that are currently found, our interviews suggest that steady availability, selective transparency, high authenticity and mutual trust are also the enablers for future applications in SCM. DLT based automation is enhanced with smart contracts. In order to trigger pre-defined actions, smart contracts require data availability, transparency and authenticity on defined

[3] In public BCT, the selective transparency is not natively given. However, most of the studied DLT initiatives use private BCT.

[4] E.g. Quorum uses the base code of Ethereum (Go Ethereum) but is permissioned in terms of reading and writing [29]

events. As DLT solution provider 3 stated: *"Smart contracts are only accepted in a trusted environment that is the case when event data is available, transparent to all affected parties and these parties are able to verify the integrity of event data."* Thus, FC4 to FC7 build the corner stones for DLT-based automation, an application that is discussed in literature but is currently not at the center of attention for practitioners, according to this study. Additional applications, such as self-controlling machine networks, are built on these FCs as well. These are forms of decentralized autonomous organizations (DAO) in supply chains. Like smart contracts, they require data availability, transparency and authenticity.

5. Concluding discussion and outlook

Based on one of the first large-scale, empirical-based studies on DLT in SCM, the study revealed seven FCs. Thereby, the study contributes to the need to understand the foundation of DLT for SCM and help guiding both practitioners and academics on this topic. First, FC1-FC3 refined the nature of DLT in SCM and disclosed that DLT is an IOIS to manage supply chains, allows for heterogeneous applications and enables platform ecosystems, which are not limited to a single application but rather increase in power when different applications are combined. FC4-FC7 describe the characteristics of the technology for SCM. As revealed, the characteristics are on two different levels that have been mixed up by previous literature as illustrated in sub-section 2.2. This study structures these characteristics. On the second level, the study indicated that DLT enables steady data availability, selective transparency, high authenticity and mutual trust in supply chains. Thereby this study helps especially SMEs and larger companies that have not explored DLT to understand the value of the technology for SCM and improve their position to make an assessment on the potential of DLT from their perspective. Moreover, Figure 1 allows practitioners to identify important characteristics to achieve a certain goal with a DLT initiative. Thus, this study enables practitioners to focus on specific characteristics when developing the DLT initiative. When revisiting the characteristics in literature, the study revealed that disintermediation, automation and tokenization do not play a significant role in current applications. This illustrates a gap to existing literature [e.g. 7, 34] that indicated that practitioners are starting to build their DLT applications on different characteristics than illustrated by academics. This is also emphasized in the form of the three major applications, proof of origin, trade financing and trade documentation that do not include drastic changes to the current supply chains, unlike the media and scientific expectation [9].

Moreover, the framework presents a testable model that can be used to study different applications of DLT in the field of SCM. Furthermore, it helps to guide future research as the framework illustrates the interplay between the different characteristics. Thus, future research can address these relations or take into account the connections between these characteristics, for example when studying specific characteristics. Furthermore, our data has only indicated the importance of the integration of DLT into the existing IT landscape and the integrative character of DLT in few cases (9%). However, this is an important topic and future research should address both the integration of DLT into existing IT (incl. physical hardware such as sensors) but also the integrative character of DLT.

6. References

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